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EVALUATION OF FAILURE MODES AND REDESIGN OF SERT II GIMBAL PIN PULLER

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16. Abstract

During vibration testing of the SERT II spacecraft, a failure of pin pullers prompted a testing program to determine the basic failure mode and to redesign the unit. By the use of high-speed motion pictures during vibration testing it was determined that the combination of torsional and axial loading failed the shear pin. It was also discovered that the testing sequence governed the failure mode. This frictional loading was reduced and the galling was eliminated by inserting a nylon bushing between mating parts. The shear pin was relocated behind the piston-and-pin assembly to eliminate the torsional failure mode.

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SUMMARY

The pin pullers employed to load the gimbals during launch on the SERT II (Space Electric Rocket Test) program encountered a problem of failure of the aluminum shear pin during vibration testing. A steel shear pin was tried and passed all vibration testing. However, due to the higher strength of the steel shear pin, an extensive reevaluation program would have to be performed. It was decided to try to determine the basic failure mode and to redesign using the maxi mum number of qualified elements of the unit.

High-speed motion pictures were taken during a experimental vibration test. These showed that after the shear pin broke, the pin rotated and did not retract into the body of the unit. This indicated that during vibration the pin was galled sufficiently to permit the torsional moment to break the shear pin.

The redesigned pin puller consisted of moving the shear pin behind the piston-and-pin assembly to allow the assembly to rotate freely. An experimental model was tested and passed all vibration testing. A prototype model was also vibrated. It failed during the third axis of testing. After comparing the two vibration tests, it was concluded that the sequence of vibration had been reversed. Visual inspection also indicated that the pin had been galled sufficiently in the first two axes to allow an axial failure during the third axis.

To solve this problem a nylon bushing was inserted between the pin and the component mounting bracket. This addition reduced the frictional forces and eliminated the galling. The redesigned pin puller with the added bushing passed all vibration, thermal vacuum, and firing tests.

INTRODUCTION

Pin pullers are used in spacecraft to provide relatively rigid mechanical coupling of components during the launch phase of the flight. These are electroexplosive devices incorporating a piston-and-pin assembly actuated by the ignition of an explosive charge. The ignition of the charge is accomplished by passing a current through a bridge wire packed in the explosive charge. A typical pin-puller assembly is shown in figure 1.

The SERT II (Space Electric Rocket Test) program used pin pullers to fasten thruster gimbal rings and other experimental apparatus to the spacecraft during launch. The pin pullers were a double-squib, single-bridge-wire configuration and were of the type in which the exploding charge drives the piston back into a housing thus retracting the pin. A shear pin placed through the piston-and-pin assembly is used to hold it in place until the charge is fired. A tapered endcap is used to retain the piston after firing. The configuration is shown in figure 2.

The pin pullers employed to stabilize the thruster gimbals encountered a problem of failure of the shear pin. The failure occurred during qualification vibration testing of the spacecraft. After vibration in the first two axes, the x and y, the pins were found retracted into the housing of pin puller, indicating failure of the shear pins. The retraction of the pin is shown in figure 3. This failure permitted damage to other components. It was determined from vibration data that the pins retracted during the y axis of vibration, but the exact time of failure could not be determined.

The first solution proposed was to replace the aluminum shear pins with steel shear pins which had two times the shear strength of the original aluminum. Tests showed that the steel pins would pass the vibration requirement. However, the higher shear strength of the steel pins required reevaluation of the squibs to determine if the powder charge was sufficient to break the shear pin and to retract the piston-and-pin assembly under load. This approach was declined because of the limited number of pin pullers available for testing, the long lead time needed for ordering new ones, and the subsequent impact on the schedule of the spacecraft. In addition, if the tests indicated that a larger powder charge was required the pin-puller body and endcap would require reevaluation to determine if these parts could withstand the higher pressure developed by the larger powder charge.

This shear pin failure prompted a testing program to determine the basic failure mode. This report describes the determination of the failure modes, the redesign, and the test program effort to obtain a successful unit with maximum conservation of qualified elements of the unit, minimum cost, and minimum schedule impact.

ANALYSIS OF THE PROBLEM

To determine the actual mode of failure, a study was made of the mounting configuration and assembly tolerances of the system. The direction of the loads in each axis that were thought to be the major cause of failure are shown in figure 2. Calculations were made to determine the magnitude of the axial shear force, the torsional moment, and the bending moment required to shear the pin. These calculations showed that an axial shear force of 66.8 pounds force (297 N) would shear the pin, while a torsional moment of 8.45 inch-pounds (0.955 N-m) would be needed to shear the pin. The configuration is such that it is difficult to shear the pin by a bending moment and, therefore, this mode of failure did not appear to be likely. The torsional mode of failure was also considered unlikely because of the installation configuration. In the z-z axis the load is axial, which would then be the major failure mode in this axis. In the x-x and y-y axis, however, if a failure occurs it would have to be a combination of torsion and bending or cross coupling through the z-z axis.

To test these conclusions, it was decided to run an experimental program with high-speed motion pictures to record the actual time of failure and, if possible, the mode of failure. The test program consisted of a sine and random vibration test first at flight levels and then at qualification levels in three axes. The pin puller passed the flight levels and the qualification level sine tests without failure. However, a failure of the shear pin occurred after 1 minute of the random vibration tests in the x axis at qualification levels. This was indicated in the motion pictures by the fact that the pin started rotating after failure. The rotation of the pin is indicated in figure 4. The pin did not retract into the body of the pin puller. The results of these experiments indicated that the system was loose enough so that during vibration testing the pin was able to gyrate in the component bracket to produce a force which was able to exceed the 8.45 inch-pounds (0.955 N-m) torsional moment needed to break the shear pin.

REDESIGN OF PIN PULLER

Although the experimental program indicated a failure in the torsional mode, it was still felt that the axial mode was a very likely failure mode. Therefore, the first redesign consisted of a configuration which would reduce the friction between the pin and the component and, therefore, reduce torsional and axial forces. It consisted of a nylon bushing placed between the pin and the component bracket, as shown in figure 5(a). This configuration was not pursued because an existing piece of assembled hardware would require remachining and the proposed schedule would not permit the loss in time.

A second configuration considered was to place the shear pin behind the piston as shown in figure 5(b). This configuration would allow the piston-and-pin assembly to rotate. It would eliminate torsional and also bending modes of failure but would not eliminate the axial load on the shear pin. However, because the motion pictures taken during the previous test program indicated a torsional failure mode, and did not indicate an axial failure mode, it was decided to test this configuration. The configuration passed vibration tests at qualification levels and was also successfully fired after testing.

This configuration was then modified to the configuration shown in figure 6 because of the possibility that the shear pin might wedge between the piston and the pin-puller body and stop full retraction of the piston-and-pin assembly. The modified design consisted of a secondary piston placed behind the main piston with the shear pin relocated in a new endcap. This configuration retained the features which eliminated the torsional and bending failure modes but prevented any chance of binding between parts.

QUALIFICATION TESTING OF NEW DESIGN

In the first experimental tests of the new design, an engineering model of the pin puller was successfully vibrated at qualification levels and one of the pin pullers was successfully fired. A qualification vibration test was then conducted on a prototype pin puller. The shear pin failed during the random vibration test in the z axis, which was the final test. An inspection of the pin-puller assembly indicated that the extended end of the pin was galled. Although similar galling had been noted in tests of the engineering model, no failure had occurred. A review of the testing procedure of the two models indicated a different sequence of tests in the three axes. In the tests of the engineering model the axis sequence was z-y-x, whereas in the prototype tests the axis sequence was x-y-z. It was concluded that the pin was galled sufficiently in the x and y axes to raise the coefficient of friction enough to cause an axial failure in the z axis.

The results of this test program indicated that the axial failure mode was also important and that the axial force must be reduced. The design proposed was the configuration first considered of placing a nylon bushing in the component bracket secured by the pin (fig. 5(a)). By doing this, the coefficient of friction would be reduced from about 0.8 to 0.3, which is a factor greater than 2. Calculations indicated that a steel shear pin will withstand 105 pounds force (467 N) and an aluminum shear pin will withstand 67 pounds force (300 N). The steel pin passed all vibration tests and the aluminum pin did not, which indicated that the axial force is somewhere between 67 and 105 pounds force (300 and 467 N). This suggested that a reduction of friction of 2:1 would reduce the axial load to less than 67 pounds force (300 N), which would permit the aluminum pins to pass the vibration tests. An additional margin would be obtained in that the nylon bushing would prevent galling, thus preventing axial force buildup. No other practical method of reducing the axial force was apparent and, therefore, it was necessary to adopt this redesign in spite of the previous objections. A vibration qualification test was run in the x axis first, followed by tests in y and z axes. The configuration passed all vibration, thermal vacuum, and firing tests. The redesigned pin pullers together with the nylon bushings are shown in their final configuration mounted on the spacecraft in figure 7.

CONCLUDING REMARKS

The pin pullers used on the SERT II spacecraft encountered vibration test failures of the shear pin designed to prevent inadvertent retraction of the piston-and-assembly. Calculations and tests were not conclusive. The calculations tended to indicate an axial mode of failure and the tests indicated a torsional mode of failure. During the redesign and test program it was found necessary to reduce both the torsional and the axial failure modes. The redesigns chosen to reduce these failure modes eliminated the torsional mode, reduced the axial mode, and also eliminated the bending mode.

It is important to note that the order of vibration testing was relevant as to whether a failure would occur. If the pin puller was vibrated in the z and y axes first and then the x axis last, no failure would occur. On the other hand, if it was vibrated in the x and y axes first followed by the z axis, a failure would occur due to galling between mating parts that occurred in the tests in the first two axes. The nylon bushing reduced the axial and torsional forces and may have been sufficient to solve the problem without the other design changes.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, August 26, 1970,
704-13.

APPENDIX - CALCULATIONS

Torsional moment:

$$S_s = \frac{M_T}{R2\pi r^2}$$

$$M_T = S_s R^2 \pi r^2$$

where

S_s shear strength, psi (N/m^2)

M_T torsional moment, in.-lb (N-m)

r radius of shear pin, in. (m)

R radius of piston, in. (m)

Shear force:

$$S_s = \frac{F}{A} = \frac{F}{2\pi r^2}$$

$$F = S_s 2\pi r^2$$

where

A cross-sectional area of shear pin, in.^{2} (m^2)

F force, lbf (N)

The values used in the preceding equations are

$$R = 0.125 \text{ in. } (0.3175 \text{ cm})$$

$$r = 0.02 \text{ in. } (0.051 \text{ cm})$$

$$S_s(\text{Aluminum}) = 27\times10^3 \text{ psi } (19\times10^7 \text{ N/m}^2)$$

$$S_s(\text{Steel}) = 42\times10^3 \text{ psi } (29\times10^7 \text{ N/m}^2)$$

The results of the calculations are shown in the following table:

	Aluminum pin	Steel pin
Axial force, S_s, lbf (N)	66.8 (297)	105 (467)
Torsional moment, M_T, inl-lb (N-m)	8.45 (0.955)	13.2 (1.49)

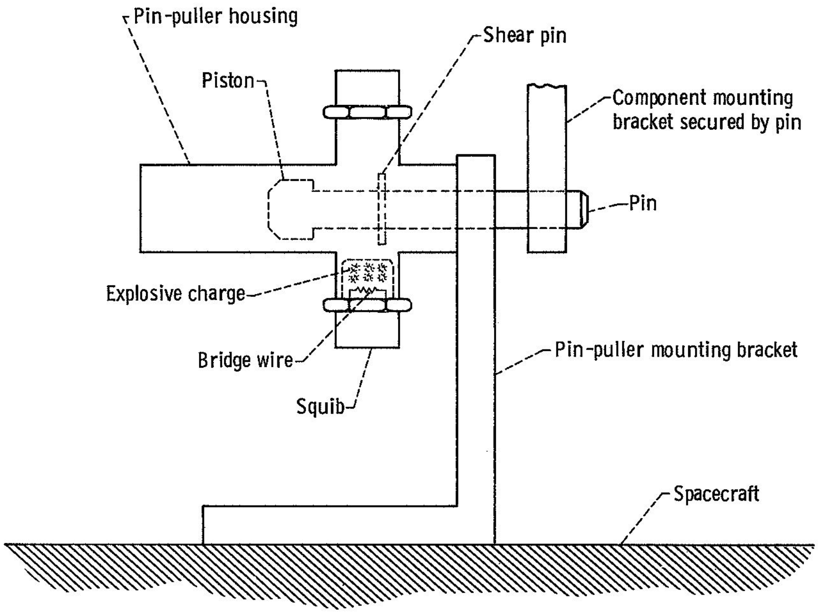

Figure 1. - Typical pin-puller assembly.

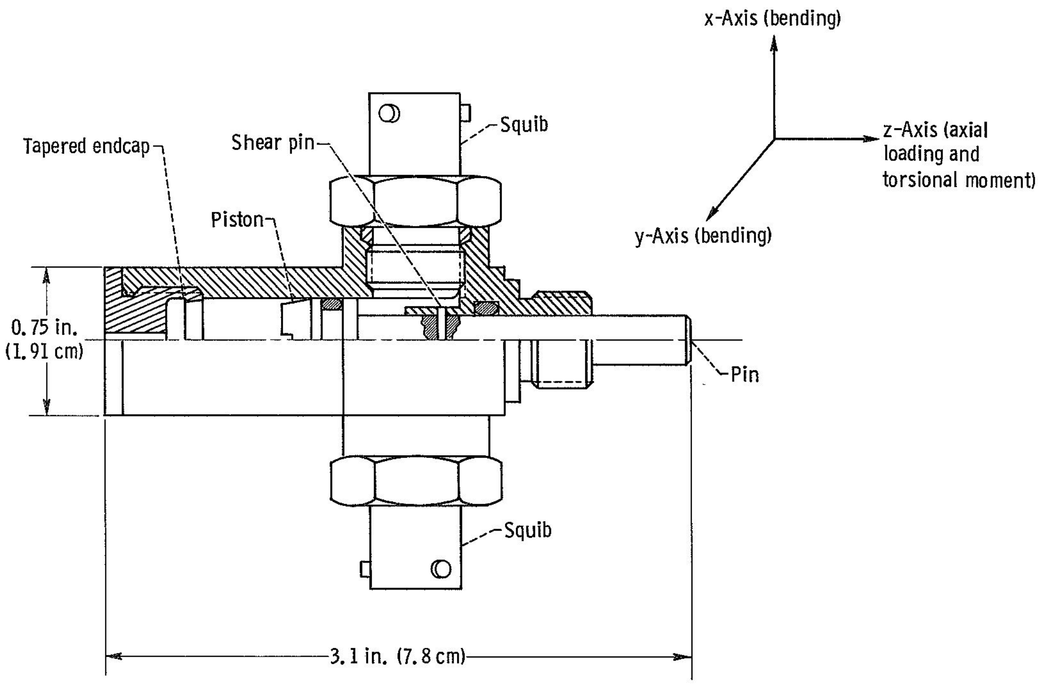

Figure 2. - Quarter section of gimbal pin puller.

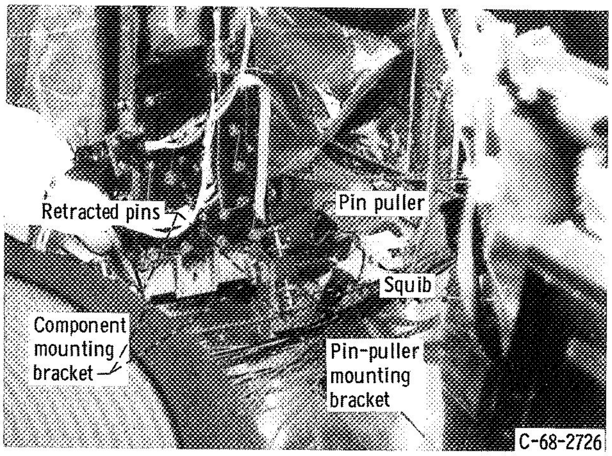

Figure 3. - Retraction of pins.

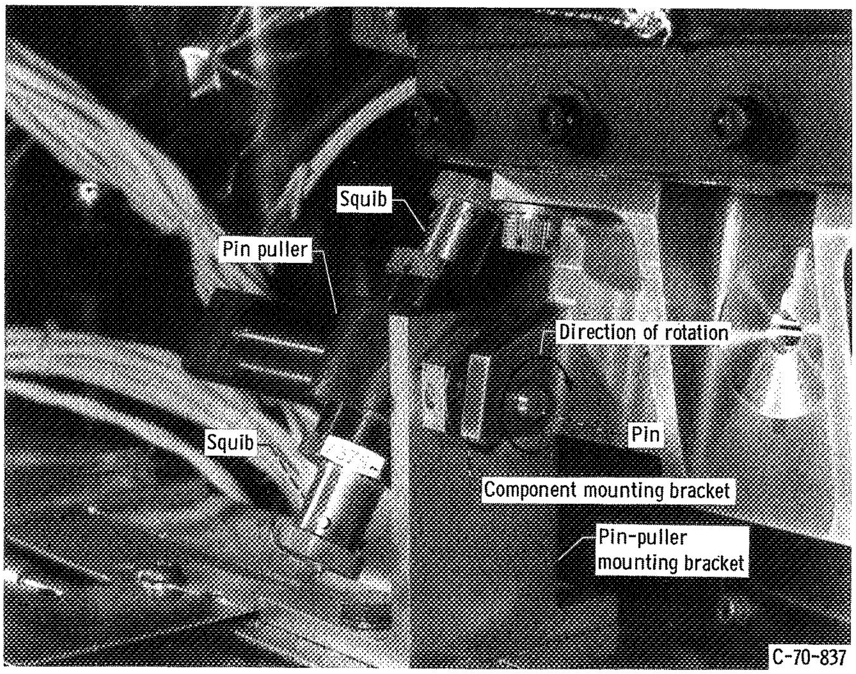

Figure 4. - Rotation of pin.

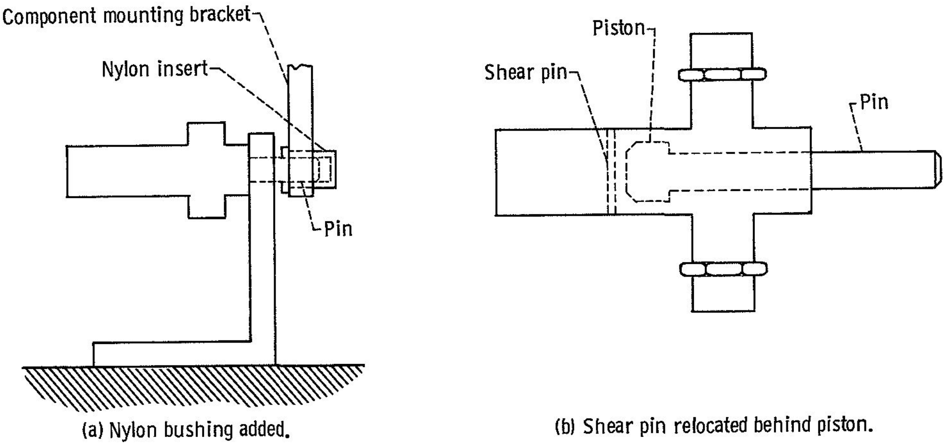

Figure 5. - Redesign concepts of pin-puller configuration.

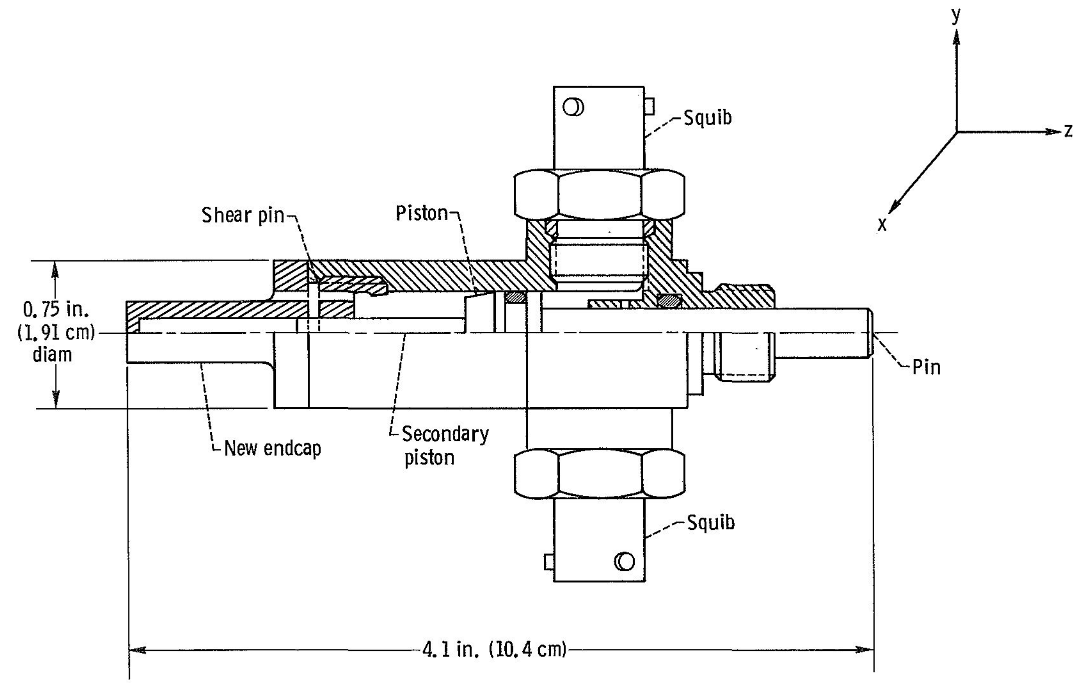

Figure 6. - New design of gimbal pin puller.

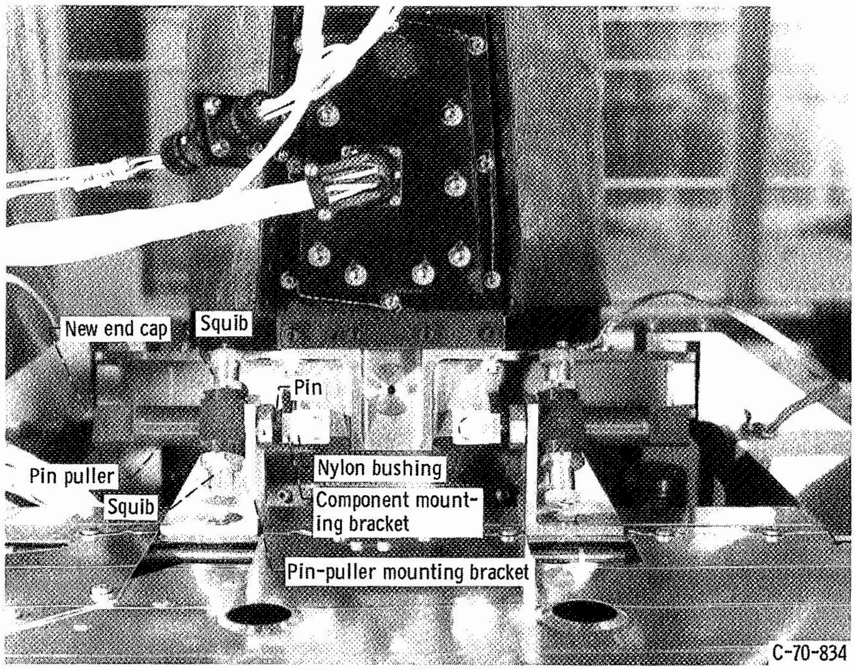

Figure 7. - Final pin-puller configuration mounted on spacecraft.

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